

SOME CHARACTERISTICS OF ULTRA-HIGH-FREQUENCY TRANSMISSION

BY

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currents in the two halves were in phase. It should be noted that the transmitter was located at the middle of this antenna and formed an integral part of it.

Receiver. A superheterodyne receiver was chosen as the basis for the field measuring equipment. The set used was a modified National type H.F.R. The indicating meter was placed in the plate circuit of the second detector. The input to the receiver was made through a one-micromicrofarad fixed condenser. For the field intensity work the set was suspended in the tonneau of a Studebaker touring car. The receiving antenna was a 2.75-meter aluminum tube with one end secured in a ball-and-socket joint in the roof of the car directly above the receiver. From the inside of the car it was possible to orient the antenna in any direction. When vertical, the top of the receiving antenna was 4.8 meters above the ground.

Calibrating equipment. This consisted of (1) a shielded 5.1-meter oscillator; (2) a variable coupling unit to the oscillator carrying energy to (3) a fixed coupling unit with primary and secondary coupled inductively; (4) an attenuator system; and (5) a shielded receiving booth. For purposes of calibration the receiver was removed from the car and placed in the booth both before and after a set of field measurements.

The input to the attenuator was made from the secondary of the fixed coupling unit. The attenuator unit consisted of a twisted pair of insulated copper wires running down the center of a long brass tube four centimeters in diameter. This tube furnished a shielded path for the attenuator system between the oscillator and its associated coupling units, and the receiver inside the booth. The pair was grounded at the end in the receiving booth, and a tap was brought out radially from one of the wires at a distance of seven centimeters from the grounded end. The potential difference between this tap and the ground constituted the output of the attenuator and was coupled to the receiver. A radio-frequency current indicating device was introduced between the variable and fixed coupling units. It can be shown that the current measured at this point was at all times proportional to the output of the attenuator.

To measure radio-frequency voltages one frequently resorts to the vacuum tube voltmeter, calibrating this instrument at commercial frequencies. At the higher radio frequencies, however, the shunt admittance of the tube is of sufficient magnitude so that appreciable current passes and a serious error is introduced. This source of error can be materially reduced provided the impedance of the branch, across which the voltage is measured, is small compared to the input impedance of the voltmeter. This fact was utilized in the calibration method, since

the output impedance of the attenuator was very small compared to the input impedance of the receiver. Accordingly, a vacuum tube voltmeter, also of a high impedance, could be used to measure the same voltages that operated the receiver by coupling the vacuum tube voltmeter to the attenuator in place of the receiver. The vacuum tube voltmeter was calibrated over a range of somewhat lower radio frequencies by the use of an inductance potentiometer.⁵ As this calibration disclosed no marked trend of voltmeter sensitivity with frequency, the calibration was used with assurance at the ultra-high frequencies.

Since the radio-frequency current meter between the variable and fixed coupling units indicated the attenuator output or receiver input within a constant factor, the measurement of a single attenuator output voltage sufficed to permit the receiver calibration to be made in absolute units, i.e. microvolts. In order to give field strengths in microvolts per meter when the receiver was used in the automobile, the receiver input voltages were divided by a factor involving the effective length of the car antenna.

ATTENUATION CURVE

The equipment described was used for a field strength survey of the 5.1-meter transmitter in Ann Arbor, Michigan, and vicinity. The results of part of this work are shown in Fig. 2. Readings were made in all directions from the transmitter, and in order to reduce the effect of the topographical variations it was attempted to make readings at points having as little shielding as possible and with intervening territory of about the same elevation. It can readily be seen that such points are limited. There are two extremes: (1) points in a direct line of observation were sometimes much higher than the intervening territory, and consequently at these points the magnitude of the electric vector approaches the theoretical inverse distance relationship, a value higher than the same point would give if the intervening territory were of the same elevation. Such points will be somewhat above the curve. Points with intervening territory of the same elevation were very few, most points being partially shielded by land of higher elevation. (2) Points thus shielded, which are in the majority, will give a field strength somewhat too low in value. For these reasons, the final attenuation curve must be between these two extremes. The second group mentioned above predominates, hence, the curve must be drawn so as to cover the higher values of this last mentioned group of points.

⁵ A. W. Hull and N. H. Williams, "Determination of elementary charge E from measurements of shot effect," *Phys. Rev.*, vol. 25, no. 2, p. 160; February, (1925).

Due to reflections and the arrival of waves by different paths, interference effects were noted at certain locations. The signal passed from a maximum to a minimum value at intervals of a few meters along the ground. Such patterns were observed only at a few locations and here an average value was taken to represent the field strength. The values of field strength are uniformly low within about one kilometer of the transmitter, since within this radius the presence of steel frame buildings furnished considerable shielding for the receiver at ground level.

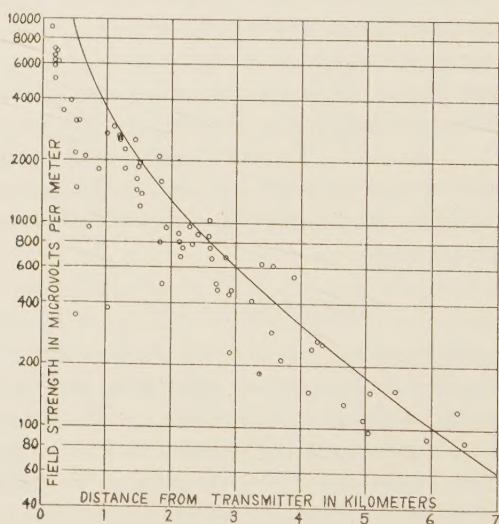


Fig. 2—Attenuation curve for 5.1-meter radiation. $\alpha = 0.36$.

ATTENUATION CONSTANT

Using points on the experimental attenuation curve, it is possible to obtain the law connecting the variables involved. The equation is of the type

$$E = \frac{K}{r} e^{-\alpha r} \sin \theta$$

where,

E = field strength in microvolts per meter

K = constant dependent on antenna height, antenna current, etc.

r = radial distance from transmitter

α = attenuation constant, dependent on nature of the terrain and on the wavelength

θ = angle that the radius vector makes with the transmitting antenna.

It should be pointed out that this equation applies to a spherical mode of radiation from an antenna and is the one best suited for the conditions encountered; i.e. the inverse distance term times the additional attenuation factor $e^{-\alpha r}$ approaches more closely to the actual conditions than would either an inverse square root or an inverse square of the distance term multiplied by the same additional attenuation factor.

Choosing any two points on the curve one can obtain the corresponding values of E and r . Then,

$$E_1 = \frac{K}{r_1} e^{-\alpha r_1} \sin \theta_1$$

$$E_2 = \frac{K}{r_2} e^{-\alpha r_2} \sin \theta_2.$$

Provided both points are at a sufficient distance from the transmitter so that $\sin \theta_1$ and $\sin \theta_2$ may be considered as unity, a solution for α reduces to,

$$\alpha = \frac{\log_e \frac{E_1 r_1}{E_2 r_2}}{r_2 - r_1}.$$

The value of α from the experimental curve is 0.36. K. Sohnemann⁶ stated that α had a value between 0.3 and 0.5 for different sections of Berlin and vicinity. F. Schröter⁷ proposed an attenuation factor of the type $e^{-\alpha r(d-h)/(H-h)}$.

Here,

r = radial distance from transmitter

d = height of absorbing layer such as is produced by buildings and trees

H = height of transmitting antenna

h = height of receiving antenna.

This form of attenuation factor would permit an inverse distance propagation between a transmitting and a receiving antenna located above the absorbing layer. The height of the absorbing layer is essentially the height of the surrounding obstacles. In the case of the transmitting antenna employed at the University of Michigan, d and H were essentially equal and therefore $(d-h)/(H-h)$ was equal to unity. Hence, the attenuation factor as proposed by Schröter becomes the

⁶ K. Sohnemann, "Feldstärkemessungen in Ultrakurzwelengebeit," *Elek. Nach. Tech.*, vol. 8, no. 10, pp. 462-467; October, (1931).

⁷ F. Schröter, "Zur Frage des Ultrakurzwelken-Runkfunks," *Elek. Nach. Tech.*, vol. 8, no. 10, pp. 431-436; October, (1931).

same as the one employed in this experimental study. It should also be noted that the attenuation constant, α , as used in this investigation



Fig. 3—Field strength contour map of Ann Arbor, Michigan, and vicinity. (58.8 megacycles.) Field strengths given in microvolts per meter. Scale 1: 125,000 or one inch equals two miles. Elevation contour interval 20 feet.

differs from that employed by Jones,¹ who used an α which was essentially independent of the wavelength.

FIELD CONTOUR MAP

In addition to the readings for the attenuation curve, field strength data were taken over a period of several weeks for the purpose of obtaining a field strength contour map. The map of Fig. 3 shows the field strength contours for the area over which measurements were made. The numerals in the contour lines indicate the field strength in microvolts per meter.

The contour lines show the general trend of the field strength. It is to be noted that the transmission appears more favorable where valleys run radially to the transmitter. At locations in the vicinity of Ann Arbor the field strength shows increased values on elevated points which have intervening territory of a lower elevation between them and the transmitter. The shielding effect of ranges of hills is also shown, although considerable filling-in behind such obstructions does take place.

In addition to the above quantitative measurements, numerous headphone observations were conducted at greater distances, with the transmitter audible as far as Toledo, Ohio, a distance of more than 80 kilometers south of Ann Arbor. In this case, the receiver was 200 meters below the line of sight from the transmitter. For both the contour map and the attenuation curve data, the transmitter antenna was maintained in a vertical position.

VARIATION OF RECEIVER INPUT WITH ANTENNA LENGTH

Fig. 4 gives the results of an experiment in which the receiver input was measured for a vertical receiving antenna shortened by successive steps. For a nonresonant condition the input voltage varies nearly linearly with antenna length. This is seen to be the case where the antenna length is small compared to the wavelength. For a resonant condition the input voltage rises beyond that which one would expect for a linear performance. In other words, an antenna approaching a resonant condition performs as if it were a nonresonant antenna of much greater length.

It should be noted that the section *F* to *J* is essentially a duplicate of *A* to *F*. The upward trend of the points *A*, *F*, *J* is due to the increased pick-up of the antenna as it was raised clear of the earth. This experiment was conducted with the receiver below the line of sight from the transmitter.

The curve shows that the resonant points occur at half-wave intervals; the best length, however, appears to be $n\lambda/2$, where n is odd. The

¹ *Loc. cit.*, pp. 360-361.

fact that n must be odd for maximum resonant effect is due to nodes and loops along the antenna which tend to cancel effects for n even.

An inspection of Fig. 4 reveals the fact that the distance between successive corresponding maxima is 5.1 meters. That is, the distance between the odd half wavelength maxima, C and G , is 5.1 meters as is also the distance between the even half-wave resonant points, E and I . The distance of 5.1 meters is the same as the wavelength of the received radiation. The first half-wave maximum, C , does not occur at a wire length equal to one half of the wavelength used, since there is an

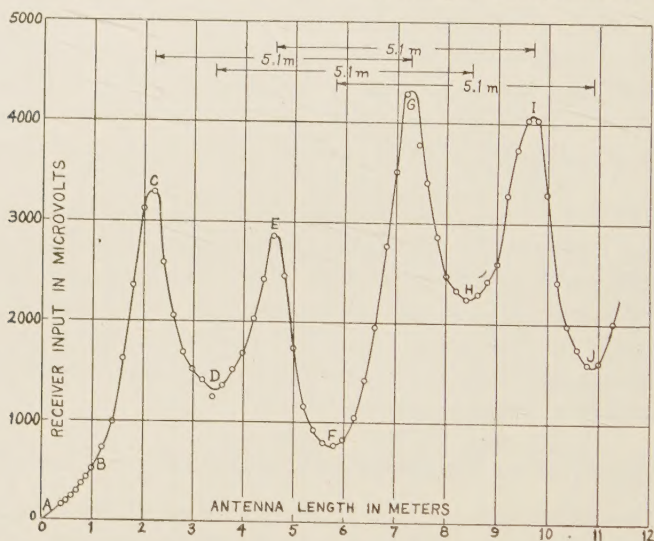


Fig. 4—Curve showing effect of antenna length on receiver input. Wavelength of received radiation 5.1 meters. Receiving antenna vertical and located 2.7 kilometers distant from the transmitter.

end effect present on the antenna. This end effect is, however, present also for the higher half-wave resonant points and is eliminated by taking the difference of the wire length for two maxima. In order to obtain the wavelength of the received radiation it is important, however, that the two maxima chosen for this difference be of the same type, i.e. odd or even half-wave resonant points. This indicates the presence of another end effect which is not the same except for maxima of the same type. By choosing the proper maxima, the end effects will be constant for both of the maxima, and when their difference is taken the end effect error is eliminated.

For example, the distance between the two maxima, C and E , is not one-half wavelength. Neither is the distance from E to G , since C and G are at odd half-wave maxima, and E is at an even half-wave max-

imum. The distance between C and G , however, is one wavelength to a high degree of approximation. The same statements hold true for the minima, the distance between successive corresponding minima being 5.1 meters.

The insertion of small tuned traps or "phase shifters" at the half-wave intervals produced a marked increase in voltage available to the receiver. A system of this type has been called a Franklin antenna.⁸ As an example, a uniform wire antenna 7.3 meters long gave an input to the receiver of 3800 microvolts. When two phase shifters were inserted at the proper points, the receiver input was increased to 7450 microvolts.

TRANSMITTING ANTENNA ROTATIONS

The rotation tests were conducted for the purpose of making measurements of the field distribution around a dipole antenna of the type used. In investigations of this nature which have been conducted at longer wavelengths, it was customary to use a fixed transmitting antenna and to measure the field distribution with a portable receiver. This method imposes limitations on the number of planes in which measurements can be made.

Owing to the shortness of the wavelength used in this investigation, it was possible to make the transmitting antenna assembly dirigible as was indicated in the description of the transmitter. In this way the receiving equipment could be located at a fixed point and the transmitting antenna given various orientations.

The types of antenna rotation divide themselves into three distinct groups: (1) rotations of the antenna in the horizontal plane, (2) rotations in a vertical plane perpendicular to the radius vector, and (3) rotations in a vertical plane parallel to the radius vector.

The equation giving the value of E at any point when the radiator is a doublet is⁹

$$E = \frac{120\pi h I}{r\lambda} \sin \theta \text{ volts per cm.}$$

For the case where h , I , λ , and r are each constant,

$$E = K \sin \theta, \text{ where } K = 120\pi h I / r\lambda.$$

By variations of the antenna in a horizontal plane, θ could be varied, and in this way the receiver input could be obtained as a function of the transmitting antenna position.

⁸ P. P. Eckersley, "The calculation of the service area of broadcast stations," *Proc. I.R.E.*, vol. 18, no. 7, pp. 1181-1182; July, (1930).

⁹ L. B. Turner, "Wireless," Cambridge University Press, pp. 23-34, (1931).

The curve of Fig. 5 shows the effect of a horizontal antenna rotation in the horizontal plane on the receiver input. The car receiving antenna was maintained in a vertical position. The transmitting antenna was

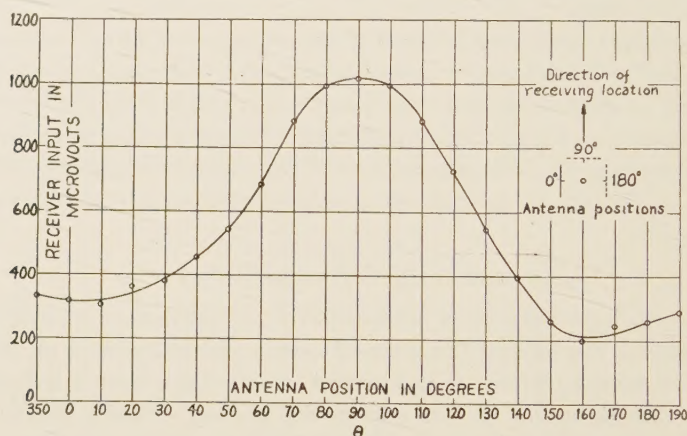


Fig. 5—Results of horizontal transmitting antenna rotation in horizontal plane. Distance of receiving location 4.28 kilometers (58.8 megacycles).

rotated through 200 degrees. At 90 degrees the transmitting antenna was perpendicular to the radius vector from the transmitter to the receiver and for this condition the received field strength was a max-

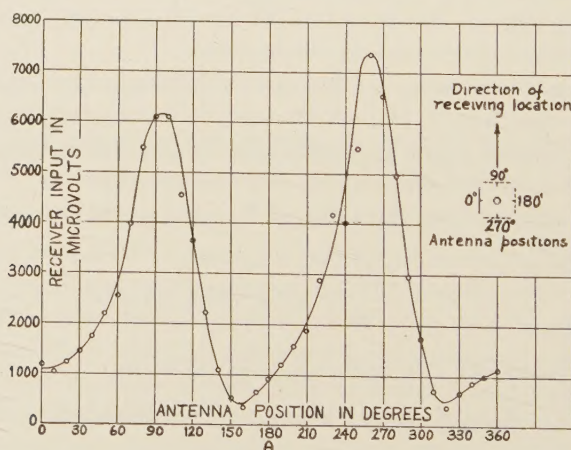


Fig. 6—Results of horizontal transmitting antenna rotation in horizontal plane. Distance of receiving location 1.82 kilometers (58.8 megacycles).

imum. Fig. 6 shows the results of a similar test conducted with the receiver at another location, and with the transmitting antenna rotated through 360 degrees. The maximum field strengths occurred at

approximately the 90-degree and 270-degree positions which correspond to a transmitting antenna position perpendicular to the radius vector.

Again using a fixed vertical receiving antenna, the transmitting antenna was rotated in a vertical plane perpendicular to the radius vector. Under these conditions the angle θ was a constant. However, the angle ϕ , which the transmitting antenna made with the horizontal, was varied through 180 degrees. The results of such a test are given in Fig. 7, in which the variation approaches closely to that expected for a sine relationship. This is to be anticipated since the vertical component of the electric vector for the various transmitting antenna posi-

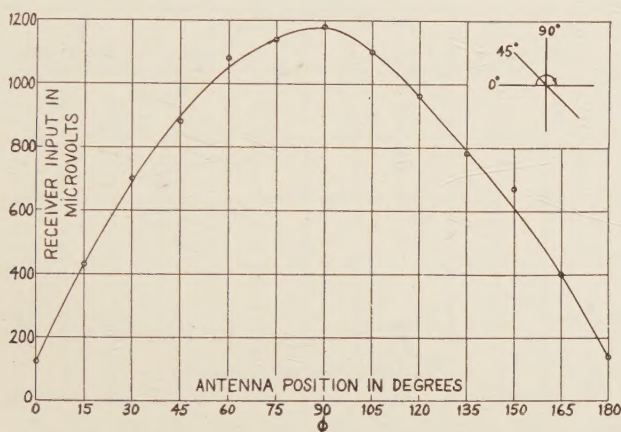


Fig. 7—Results of transmitting antenna rotation in a vertical plane perpendicular to the radius vector. Insert at upper right shows antenna rotation as "viewed" from receiving location. Receiving antenna vertical. Distance to receiving location 2.7 kilometers (58.8 megacycles).

tions is equal to the product of the maximum value, occurring with the antenna vertical, and the sine of the angle ϕ , which the antenna makes with the horizontal.

The results of another investigation of this nature are given in Fig. 8. The solid line *A* represents the part of the test made with the receiving antenna vertical at all times. When the direction of the receiving antenna was adjusted to give maximum receiver input the variation followed the dashed curve *B*. Although this latter curve exhibits less variation than curve *A*, it is evident that the horizontally polarized wave is not as effective at a distance. In other words, it is attenuated more rapidly than the vertical. This agrees with the results obtained by Trevor and Carter² in an experiment of a different nature.

² *Loc. cit.*, p. 396.

A study of the positions of the receiving antenna as compared to the transmitting antenna, as given at the bottom of Fig. 8, indicates that the electric vector was more nearly vertical, in most cases, by the time it reached the receiver at a distance of 3.4 kilometers than it was when it left the transmitting antenna. If one assumes that the receiving antenna was able to indicate the direction of the electric vector, it would appear that at sufficient distances from the transmitter the electric vector would be essentially vertical regardless of the orientation of the transmitting antenna in a vertical plane perpendicular to the radius vector. The same, to an even greater degree, was also found to

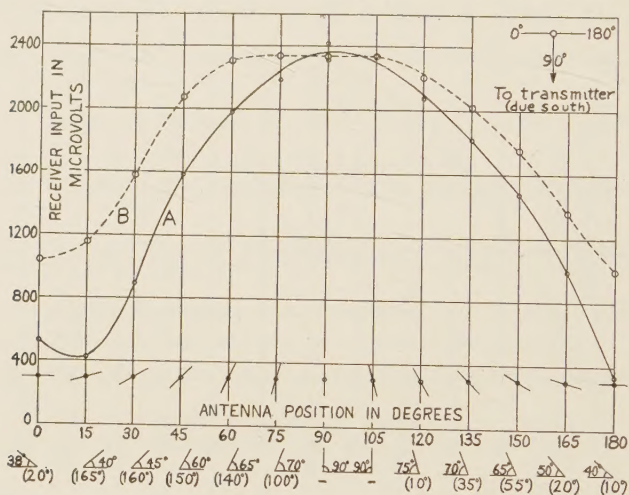


Fig. 8—Results of transmitting antenna rotation in a vertical plane perpendicular to the radius vector. For curve A (solid) receiving antenna maintained vertical. For curve B (dashed) receiving antenna position adjusted to give maximum receiver input. The figures along abscissa give transmitting antenna position in degrees (ϕ) and these positions are also indicated just above diagrammatically. The altitude of the corresponding receiving antenna positions, for part B, is indicated by the diagram at the bottom of the figure, "viewing" the receiving antenna from the same direction as the transmitting, i.e. from the south. The azimuthal angles of the receiving antenna positions are given by the figures in parentheses, and their meaning is explained by the insert in the upper right-hand corner of the figure. Receiving location 3.4 kilometers due north of transmitter (58.8 megacycles).

be true for transmitting antenna positions in a vertical plane parallel to the radius vector. It is evident, however, that similar tests must be conducted at varying distances along a straight line from the transmitter before definite conclusions can be reached. Nevertheless, when one considers a wave having both a vertical and a horizontal component of the electric vector, it is reasonable to suppose that the wave tends to become more nearly vertical as it progresses along the ground in view

of the more rapid attenuation of the horizontal component. This discussion, of course, applies to the unreflected ground wave.

The solid curve *A* of Fig. 9 shows the effect of rotating the transmitting antenna in a vertical plane parallel to the radius vector with the receiving antenna at all times vertical. The results gave a curve in which the maximum occurred for θ , which is now the variable, equal to 90 degrees, or with the transmitting antenna vertical. The curve does not appear symmetrical due to some characteristics of the transmitter-antenna unit. When the receiving antenna was adjusted to give maximum receiver input the dashed curve *B* resulted, indicating again that

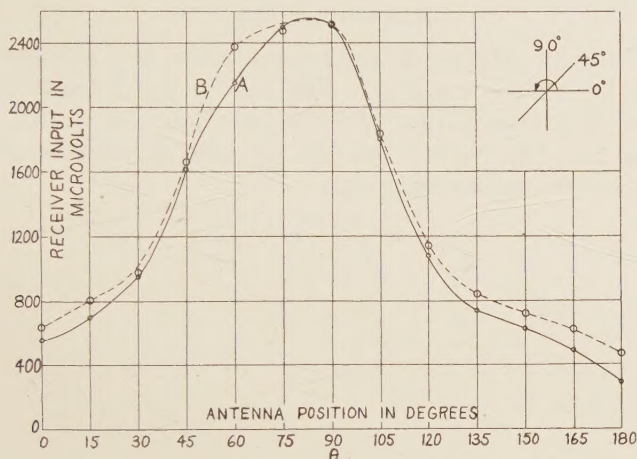


Fig. 9—Results of transmitting antenna rotation in a vertical plane parallel to the radius vector. For curve *A* (solid) receiving antenna maintained vertical, for curve *B* (dashed) receiving antenna adjusted to give maximum receiver input. Insert at upper right shows antenna rotation as "viewed" from the east of the transmitter. Receiving location 3.4 kilometers due north of transmitter (58.8 megacycles).

waves leaving the transmitting antenna horizontally polarized are attenuated more rapidly than the vertically polarized waves.

CONCLUSION

The type of field strength measuring equipment and the method of calibration as described in this paper have proved to be very effective. From the field strength surveys, and in particular the field contour map, a transmitter of low power with an input of about 15 watts is seen to be able to give a good coverage of Ann Arbor and environs. It was demonstrated that a vertical transmitting antenna has definite advantages, and, in general, for this case a vertical antenna proved best for reception.

